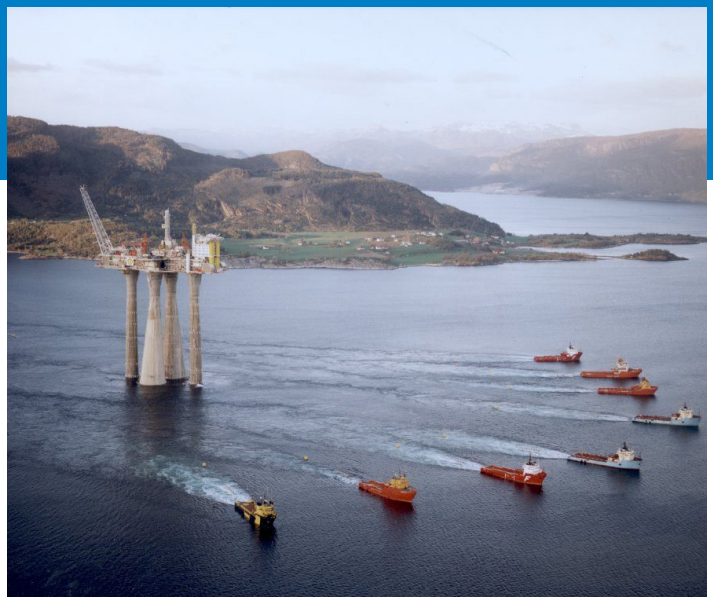
An ACI Technical Publication

SYMPOSIUM VOLUME



Offshore and Marine Concrete Structures: Past, Present, and Future

SP-337

Editor:
Mohammad S. Khan

American Concrete Institute
Always advancing

Offshore and Marine Concrete Structures: Past, Present, and Future

Sponsored by
ACI Committee 357 – Offshore and Marine Concrete Structures

The Concrete Convention and Exposition
March 24-28
Quebec City, Quebec, Canada

Editor:
Mohammad S. Khan

American Concrete Institute
Always advancing

SP-337

First printing, February 2020

Printed in the United States of America

Editorial production: Ryan M. Jay

ISBN-13: 978-1-64195-093-0

PREFACE

Offshore and marine concrete structures have not received enough attention in the recent past, at least in the United States. The complexity and safety concerns associated with these structures are such that they probably need more attention compared to many other types of concrete structures. Also, offshore and marine concrete structures are so global in nature that there is a higher need for better coordination and synchronization of design, construction, inspection, and maintenance practices in different parts of the world.

A two-part session, titled "Offshore and Marine Concrete Structures: Past, Present, and Future," was held at the Spring 2019 ACI Concrete Convention and Exposition on March 24-28 in Quebec City, Quebec, Canada. The session, sponsored by ACI Committee 357, Offshore and Marine Concrete Structures, highlighted accomplishments of the past, current state-of-the-practice, and a path for the future. This ACI Special Publication (SP) is a compilation of select papers presented at the session. The efforts of all the reviewers in assuring the quality of this publication is greatly acknowledged.

Mohammad S. Khan, Ph.D. P.E.
Editor

TABLE OF CONTENTS

Design and Construction Overview of Offshore Concrete Gravity-Based-Structures: Past, Present, and Future

Widianto, Jameel Khalifa, Erik Åldstedt, Kåre O. Hæreid, Kjell Tore Fosså

Synopsis: An offshore concrete Gravity-Based-Structure (GBS) is a massive concrete structure placed on the seafloor and held in place strictly by its own weight, without need for anchors. This paper focuses on concrete GBSs used as the base of integrated oil drilling and production platforms. The summary of key distinct structural features of several major GBSs, since the first Ekofisk GBS (installed in the North Sea, offshore Norway, in 1973) until the latest Hebron GBS (installed in the Grand Banks, Canada, in 2017), is presented. This paper also discusses several unique loads that GBSs have to resist. An overview of structural analysis and design methodology is described in detail. Key considerations for preliminary sizing of GBS structural components are presented. Typical construction phases, methods, and the importance of constructability are explained. Finally, potential future research topics that would result in a more cost-effective offshore concrete GBS are discussed.

Keywords: Floating Construction, Reinforced Concrete Design, D-regions, Structural Analysis, Offshore Structures, Strut-and-tie, Wave loads

Hebron Offshore Concrete Gravity-Based-Structure: Novel Design and Construction Techniques

Widianto, Jameel Khalifa, Kåre O. Hæreid, Kjell Tore Fosså, Anton Gjørven

Synopsis: The Hebron platform is the latest major offshore integrated oil drilling and production platform supported by a concrete gravity-based-structure (GBS). It was successfully installed in the Grand Banks (offshore Newfoundland) in June 2017. The design of the platform was challenged by arctic-like and extreme metocean conditions. This paper presents development of extreme loads on the GBS such as 10,000-year iceberg impact and wave loads. It also describes novel design and construction techniques used, which resulted in a capital-efficient platform.

From an analysis and design perspective, in addition to linear-elastic finite element analysis typically used in design of offshore concrete GBS, the innovative use of non-linear finite element analysis (NLFEA) technique to calculate internal forces is presented. Such analyses more accurately capture the structural behavior and result in more realistic internal forces. In addition, a new crack-width calculation method accounting for the effect of a significant number of layers of transverse reinforcement was implemented. Also, a novel method to assess the complex interactions between solid ballast, embedded pipes, and concrete structures was applied.

From a construction perspective, the use of slipforming panels that are taller than those used in past GBSs and a system to allow slipforming of the shaft wall with a complex geometry and curvature, that is much larger than that employed in the past GBS, are presented. A novel method to minimize the risk of concrete adhering to slipforming panels by cooling the panels with cold water is presented. An innovative method to ensure that high-strength grout completely filled the space underneath one of the largest Topsides footings is discussed. Full-scale constructability tests of various complex GBS components, which provided invaluable information for design, increased execution certainty, and improved construction safety, is presented.

Keywords: Hebron, Offshore, Design, Construction, Gravity Based, Slipforming, Crack Width, Grouting

Barbours Cut Terminal - Container Port Wharf Expansion Design

Jeremiah D. Fasl and Carl J. Larosche

Synopsis: This paper will present the challenges and unique aspects associated with increasing the capacity of one of the container wharves at Barbour's Cut Terminal to support new Ship-to-Shore (STS) container cranes with gage lengths of 100 ft. (30 m), which was an upgrade from the previous container cranes that featured 50-ft. (15 m) gage lengths. The design criteria included achieving an additional 50 years of service life from the existing elements and new elements; therefore, the assessment results and techniques used for service life modeling will be discussed. In the new structural elements, service life modeling was used to determine the necessary concrete mixture characteristics, including use of fly ash and corrosion-resistant reinforcement, to achieve the required service life.

This paper will also discuss the design approach, including the use of springs to represent the soil-structure interaction, for determining the demands on the various components. In addition, the interaction between the new structure and existing structure and the resulting torsion will be discussed. Finally, various lessons learned from using strut-and-tie modeling, including the relative stiffness of the chord elements and need for three-dimensional modeling, will be summarized.

Keywords: container crane, rehabilitation design, service life modeling, strut-and-tie modeling (STM), wharf

Testing and Inspection Techniques for Offshore and Marine Structures

Mohammad S. Khan

Synopsis: Offshore and marine structures present special testing and inspection challenges due to their difficult accessibility and lack of visibility below water. Some of the testing and inspection personnel need to be divers, and some of the testing and inspection techniques become impractical in submerged conditions even with a diver. Thus, non-destructive evaluation (NDE) techniques that can be applied from above water, coupled with limited underwater inspections, offer the most practical solution for the testing and inspection of offshore and marine structures. This paper reviews and analyzes various above-water and underwater techniques that can be used for offshore and marine structures. Above-water techniques include visual inspections, chloride ion analysis, carbonation depth measurement, half-cell potential measurement, corrosion rate measurement, strength testing, and petrographic analysis. Whereas, the underwater techniques include diver-assisted visual inspections, real-time video imaging, modified versions of some of the above-water techniques, sonic-echo, impulse response, ultrasonic guided waves (UGW), and limited semi-destructive testing. Advantages and limitations of various techniques have been discussed. Finally, areas of future research have been identified, which can improve the efficiency, effectiveness, cost, and safety of testing and inspection techniques used in offshore and marine structures.

Keywords: condition assessment, evaluation, inspection, marine, NDE, offshore, structural evaluation, underwater, testing

Concrete Mix Design Development for Offshore Structures

Kjell Tore Fosså, Widianto

Synopsis: This paper describes the development in concrete technology for offshore concrete structures from the 1970's until now and discusses some potential topics for future research which would result in more cost-effective offshore concrete structures.

Most of the offshore concrete structures constructed in the last 4 decades are still in operation, with no or only minor maintenance required, even though the average age for these structures in the North Sea is more than 25 years. The compressive strength in offshore structures has gradually increased from about 40MPa (5800 psi) in the 1970's to more than 100MPa (14500 psi) in some of the latest concrete structures. Standards and concrete specifications have been revised several times during these years. In parallel, the knowledge from several research and development programs has been used to further improve the concrete properties and overcome the limitations. Focus has been primarily to improve the compressive strength of the concrete as well as the durability and concrete workability. The cement and admixture industry have been heavily involved in research programs to further adapt and develop these material properties. The result of the product developments in the concrete constituency has also improved cost-effectiveness and durability (including overall life-cycle cost-effectiveness) for offshore concrete structures.

With the new generation technology, the technical limitations we face today will be overcome. With more knowledge and improved technology, the quantity and size of cracks in concrete in service are expected to be reduced, which would also improve durability. In addition, the focus in the future will also be on sustainable and environmentally friendly materials.

Keywords: Gravity Based Structure, Concrete Mix, Slipforming, Offshore, Aggregate, High-Strength, Cement, Admixtures, Pozzolans

Performance of Concrete in a Harsh Marine Environment for 25 Years

Edward (Ted) Moffatt, Michael Thomas and Andrew Fahim

Synopsis: In 1978, the Canadian Centre of Mineral and Energy Technology (CANMET) initiated a long-term study to determine the performance of concrete in a marine environment. Between 1978 and 1994, over three hundred prisms as part of 14 different experimental phases were placed at the mid-tide level at the Treat Island exposure site. Treat Island is an outdoor exposure site operated by the U.S. Army Corps of Engineers, and lies in the Passamaquoddy Bay, part of the Bay of Fundy, near the town of Eastport in Maine. Following 25 years of exposure, the blocks were retrieved after being exposed to tidal conditions representing approximately 18,250 cycles of wetting and drying, and 2,500 cycles of freezing and thawing. This paper presents the durability performance of concrete from several phases of the CANMET study. This includes concrete incorporating various levels of supplementary cementing materials (up to 80% by mass of cementing material in some cases), with normal density and light-weight aggregate. The paper also compares output from the service-life model Life-365 with experimental chloride profile data. The results indicate the efficacy of SCMs in increasing the concrete resistance to chloride penetration. However, use of very high levels of these materials was found to render the concrete more susceptible to surface scaling. The results also showed that Life-365 model can predict chloride penetration adequately with very simple inputs.

Keywords: marine exposure, chloride penetration, corrosion, durability, supplementary cementing materials, permeability, service life prediction.

Importance of Structural Assessment before Rehabilitation Case Study: Waterfront Concrete Pier

Pericles C. Stivaros, Varoujan Hagopian, and Alan D. Pepin

Synopsis: This paper discusses the structural assessment and repair of a waterfront concrete pier. This paper also discusses the responsibilities of the construction team through the investigation and repair process. The apron around the pier is an exposed concrete deck supported on steel beams and concrete caissons. The concrete apron exhibited various deteriorated conditions, including cracking and spalling. The pier owner requested a structural condition survey of the pier apron to determine the extent of the damage and to develop a repair program.

The design team proposed an investigation and repair program in accordance with various industry standards, including ACI 357, ACI 562, and ACI 364.1R. The challenge of this project was the limited budget and time allocated by the owner to perform the investigation and repair. As a result, the investigation was limited to visual observations only, and the repairs were restricted to repairing unsafe conditions only. Despite the investigation and repair construction limitations, the design team work around the needs and budgets of the owner and managed to restore the structure to a safe condition. However, the effects of insufficient evaluation of the structure before rehabilitation, had an adverse effect on the project schedule and extent of repairs performed. Also, due to the project budget limitations, the responsibilities of the design team were challenged.

Keywords: concrete repair, marine structures, waterfront structures, structural assessment, structural evaluation, responsibility.

LaGuardia Airport Design Build for Extending Runway Decks for Safety Area Improvements, Queens, NY

Anthony Devito, Alex Krutovskiy and Leszek Czajkowski

Abstract: The purpose of the LaGuardia Runway Extension Project is to extend existing runways 4-22 and 13-31 into Flushing Bay, at the inshore end of Long Island Sound, to support Engineered Material Arresting System (EMAS) - a crushable material installed at the end of each runway to reduce the risk of a plane overrun during takeoff.

The new runway deck extensions are marine concrete structures which utilize precast prestressed pile caps with a pre and post-tensioned composite precast deck and cast-in-place concrete topping slab. The concrete decks are supported by 250 ton (227 tonnes) 24 inch (61cm) diameter epoxy coated closed end concrete filled steel pipe piles with specialized wraps and sacrificial zinc anodes for corrosion protection. The piles are approximately 100 feet (30m) long and driven in about 30 feet (9m) of water through soft organic clay and dense glacial soils and founded on bedrock.

This paper provides an overall description of the runway extensions and a detailed account of both the technical and logistical challenges. Challenges included a prestressed composite deck design for both the aircraft impact and braking loads. Maintaining and replacing the lightbars of the Approach Lighting Systems (ALS) used to visually identify the runways was required, along with optimizing the pile hammer selection and driveability with wave equation analyses and dynamic pile driving PDA testing. Extensive coordination was necessary with the PANYNJ, FAA and various other stakeholders involved in this fast-paced design build project.

Keywords: corrosion protection, drop plank system, longitudinal braking force